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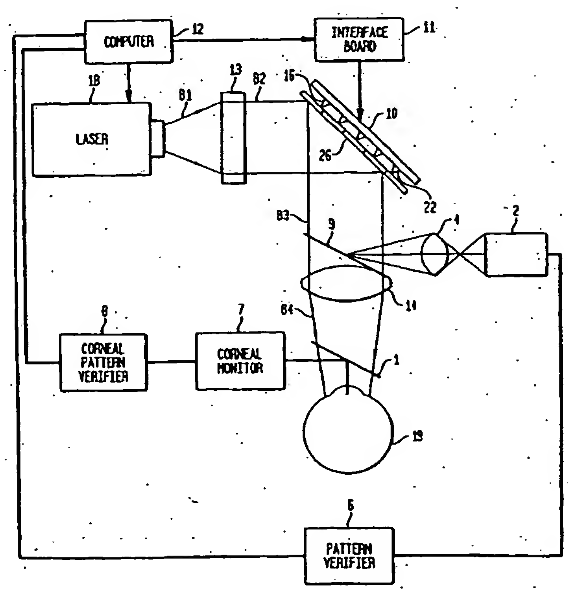
(54) Title: LASER PATTERNING SYSTEM FOR MICROSURGERY



(57) Abstract: A system and method for ablating a workpiece (19). One preferred embodiment of the invention employs a laser (18) and a digital micromirror device (10) to accomplish corrective corneal surgery using real time correction of the ablation pattern. Another preferred embodiment of the invention is an improved digital micromirror device (10) for laser ablation.

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Laser Patterning System for Microsurgery.

FIELD OF INVENTION

This invention relates to the field of ablating organic and inorganic materials and particularly to using computer controlled programmable arrays of reflecting surfaces to effect such ablation.

BACKGROUND

At the present time, ablation by laser radiation has become a common practice in diverse industrial and other processes. For example, U.S. Patent No. 5,843,383 issued to Mitwalsky et al teaches the use of laser ablation for etching through one or more layers of dielectric materials while not damaging the underlying conductive material layer. This method of laser ablation may be used to produce a desired pattern on a multi-layered workpiece.

Another common use of laser ablation is a direct replacement of common photolithography. Photolithography is the general term for the process of producing two or three dimensional patterns on semiconductor wafers and/or substrates from physical or virtual image sources. Photolithography produces layer or multilayer arrays of graphic elements, which form electronic components and their interconnections, Commonly known lithography uses the masks to project the desirable image over substrate. The laser source can be used as an illumination device or energy source. Laser serves as an illumination device in case of the chemical material processing follows initial exposure, and as an energy source in case of the direct ablation.

Laser ablation has also been used as a method of surgery in the vision correction field. This procedure is known as photorefractive surgery. In this procedure, a physician (after properly preparing the patient) cuts the cornea with a device known as a microkeratome to create a corneal flap. The physician then uses the laser to ablate a portion of the stroma in a predetermined pattern that is defined to correct the patient's vision.

In the area of photrefractive surgery, the ablation pattern is typically done using an adjustable iris and a laser beam. A drawback of this procedure is that the ablation can only be done in a circular pattern. Other method of laser photorefractive surgery includes using of the

prefabricated erodable mask. This method makes success of the surgery dependant on the quality and accuracy of mask fabrication. Prefabricated masks do not account for individuality of the cornea shapes.

Laser ablation in each of the above-described fields would be simpler and less expensive if the laser radiation could be more precisely controlled. A promising approach has been the use of a digital micromirror device ("DMD"). A DMD includes an array of small mirrors that can assume reflecting positions of "On", "Off" or "Neutral". The setting of the reflecting position would customarily be done by computer. Commercial DMDs are sold by Texas Instruments Incorporated.

Several patents have taught the use of DMDs as part of a laser ablation system. These systems assume that the reflecting surfaces assume the position commanded by the computer. These systems also assume that the reaction of each portion of the workpiece to the ablation will be uniform and that the ablation pattern projected by the DMD is as commanded by the computer. To the extent that these assumptions are incorrect, the actual ablation patterns achieved will be different than the ablation patterns that were desired.

SUMMARY OF THE INVENTION

One aspect of the invention is a system for ablating a workpiece including a device for producing pulses of electromagnetic radiation; a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions, the array thereby selectively directing portions of the pulses to the workpiece; a computer for controlling the array to achieve the desired pattern of ablation; a monitoring device for determining the amount of ablation of the workpiece after each of the pulses; and a device for providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a method for ablating a workpiece including the steps of producing the workpiece; producing pulses of electromagnetic radiation; selectively directing portions of the pulses to the workpiece using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the workpiece using a monitoring device after

each of the pulses; and providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

The workpiece that is the subject of the system and method described above may be a cornea.

Another aspect of the invention is a method for ablating a cornea of a patient to correct vision including the steps of preparing the patient; cutting the surface of the cornea and articulating the flap of tissue formed thereby; producing pulses of electromagnetic radiation; selectively directing portions of the pulses to the flap using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the flap using a monitoring device after each of the pulses; and providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a method for ablating a cornea of a patient to correct vision including steps of preparing the patient, cutting the surface of the cornea and articulating the flap of tissue formed thereby; selectively directing portions of the pulses to the main body of the cornea using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the main body using a monitoring device after each of the pulses; providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device; producing pulses of electromagnetic radiation; selectively directing portions of the pulses to the flap using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the flap using a monitoring device after each of the pulses; and providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a system for writing a pattern by ablation on a deposit layer on a silicon wafer including a device for producing pulses of electromagnetic radiation; a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of positions, the array thereby selectively directing portions of the pulses to the deposit layer, a computer for controlling the array to achieve the desired pattern of ablation, a monitoring device for determining the amount of ablation of the deposit layer after each of the pulses, and a device for providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a system for writing a bar code pattern by ablation on a workpiece including a device for producing pulses of electromagnetic radiation; a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions, the array thereby selectively directing portions of the pulses to the workpiece; a computer for controlling the array to achieve the desired pattern of ablation; a monitoring device for determining the amount of ablation of the workpiece after each of the pulses; and a device for providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a method for writing a barcode pattern by ablation on a workpiece including the steps of producing the workpiece; producing pulses of electromagnetic radiation; selectively directing portions of the pulses to the deposit layer using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the deposit layer using a monitoring device after each of the pulses; and providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a system for writing a numerical pattern by ablation on a workpiece including: a device for producing pulses of electromagnetic radiation; a

computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions, the array thereby selectively directing portions of the pulses to the workpiece; a computer for controlling the array to achieve the desired pattern of ablation; a monitoring device for determining the amount of ablation of the workpiece after each of the pulses; and a device for providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a method for writing a barcode pattern by ablation on a workpiece including the steps of producing the workpiece; producing pulses of electromagnetic radiation; selectively directing portions of the pulses to the deposit layer using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the deposit layer using a monitoring device after each of the pulses; and providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a method for writing a numerical pattern by ablation on a workpiece including the steps of producing the workpiece; producing pulses of electromagnetic radiation; selectively directing portions of the pulses to the deposit layer using a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions; controlling the array using a computer to achieve the desired pattern of ablation; determining the amount of ablation of the deposit layer using a monitoring device after each of the pulses; and providing information from the monitoring device to the computer for adjusting the reflecting positions of the reflecting surfaces of the array after receiving information on the degree of ablation from the monitoring device.

Another aspect of the invention is a computer controlled programmable array of reflecting surfaces wherein each of the reflecting surfaces may be in one of a plurality of reflecting positions, which array is enclosed in a housing at least one of whose sides is a transparent material that permits the passage of ultraviolet light.

The transparent material described in the preceding paragraph is composed of ultra-violet grade synthetic fused silica. Alternatively, the transparent material is composed of a fluorine based material. Alternatively, the transparent material is composed of magnesium fluoride. Alternatively, the transparent material is composed of fused silica. Alternatively, the transparent material is composed of lithium fluoride. Alternatively, the transparent material is composed of barium fluoride.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a laser beam modulating apparatus in accordance with a preferred embodiment of the invention.

FIG. **2** is a cross sectional view of the DMD component of a preferred embodiment of the invention.

FIG. **3(a)** illustrates the articulated flap and the cut surface of the cornea in an operation accomplished using a preferred embodiment of the invention.

FIG. **3(b)** illustrates the ablation of both the flap and the cut surface of the cornea.

FIG. **3(c)** illustrates the three-dimensional ablated hollow after the ablation and the articulation of the flap back onto the cut surface of the cornea.

FIG. **4** is a flow diagram of the logical sequence of operations of the laser beam modulating apparatus in a preferred embodiment of the invention.

FIG. **5** is a flow diagram of the logical sequence of operations of the laser beam modulating apparatus in another preferred embodiment of the invention.

FIG. **6(a)** is another preferred embodiment of the compliant support component of the invention.

FIG. **6(b)** is a third preferred embodiment of the compliant support component of the invention.

FIG. **7(a)** illustrates another preferred embodiment of the invention as applied to a corneal transplant procedure.

FIG. **7(b)** illustrates the three dimensional ablated hollow after ablation and the placement of the transplanted cornea back onto the cut surface of the cornea.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention can be used to selectively ablate a pattern on a workpiece with the utmost control up to submicron resolution. These characteristics make the broad aspects of the apparatus of the present invention suitable for a variety of uses. In one aspect of a preferred embodiment, the accuracy of the ablation makes the invention particularly suitable for refractive eye surgery while the accuracy and resolution makes it particularly suitable for various maskless patterning processes. The key feature of this invention is real time active feedback control of the pattern generation. It allows for fast automatic pattern of depth correction (both with respect to two dimensional patterns and three dimensional topology) and provides for real time control based elimination of process variations. In short, the system allows for modifications and changing of the ablation patterns on the fly.

In a preferred embodiment of the invention, a computer controlled programmable array of reflecting surfaces is used to ablate corneal tissue to achieve vision correction. Certain of the principles used in this invention may be found in U.S. Pat. No. 5,624,437, issued to Freeman et al., which is expressly incorporated herein by reference. Among other principles, the Freeman patent teaches the manufacture and use of several components including a digital micromirror device ("DMD"), which is a micromechanical device that may serve as an array of reflecting surfaces. The structure and use of DMDs have been described in Michael A. Mignardi's article "" Digital Micromirror Array for Projection TV", Solid State Technology, July. 1994. Details on DMDs, may be also found in U.S. Pat. No. 5,061,049 issued to Hornbeck and assigned to Texas Instruments Incorporated. U.S. Pat No. 5,061,049 is expressly incorporated herein by reference

It should be noted that presently available DMD's and DMD's referred to in the Freeman patent must be modified, as set forth below to be operative with radiation sources, operating at shorter than visible wavelength. Example of such sources can be UV laser, which would be typically used in a preferred embodiment of the present invention.

FIG. 2 shows a cross sectional view of DMD **10** as modified in accordance with the invention. DMD **10** is composed of a two dimensional array of micromirrors **22**. The internal environment **24** of DMD package consists of an engineered chemistry, which is necessary to extend the operational life of each of micromirrors **22**. The internal environment **24** is sealed with a transparent material **26** such as glass.

The transparent material **26** is composed of a material that must permit the transmission of ultra-violet light. In a preferred embodiment of the invention, the transparent material **26** would be composed of ultra-violet grade synthetic fused silica, or other suitable material. Also in the preferred embodiment, there would be anti-reflection coating on both sides. The preferred material for anti-reflective coating would be a fluorine based material, for example magnesium fluoride. However, other anti-reflection materials could be used, including those that have multi-layer structures. The transparent material **26** could also be composed of other materials that permit transmission of ultra-violet radiation such as fused silica, synthetic fused silica, calcium fluoride, lithium fluoride, barium fluoride and magnesium fluoride.

The anti-reflection coating also serves as a barrier to the reaction of the compounds in internal environment **24** with the compounds of which the transparent material is composed. It is particularly important, when operating in UV portion of the spectrum, since it is well known that UV is an accelerator of chemical processes.

FIG. **1** shows a schematic diagram of an ablating apparatus of this invention particularly configured for eye surgery, which includes a DMD **10**, an interface board **11**, a computer **12**, a conventional homogenizing and collimating optic **13**, and a conventional re-imaging optic **14**. Also shown in FIG. **1** is laser **18**, splitting mirror **9**, splitting mirror **1**, corneal monitor **7**, corneal pattern verifier **8**, pattern verifier **6**, lens **4** and pattern detector **2**.

FIG. **4** is a flow chart showing the sequential steps in carrying out refractive eye surgery in accordance with the invention. At step **40**, the patent is positioned and prepared for carrying out the surgery. Such preparation includes anesthetizing the eye with eye drops and using a speculum to hold the eyelids open. At step **40a** the patient fixates on a green spot to position the axis of the eye relative to the ablation axis, and the eye is measured to confirm the desired correction pattern. The desired nominal ablation pattern is then set at step **42**. At step **41** the physician cuts the cornea with a microkeratome as is presently done in a well-known procedure called LASIK, whose principles are described in U.S. Pat. No. 4,903,693 issued to Warner et al, which is incorporated herein by reference. The cut would not be completely through the surface of the cornea but would leave a small connection of tissue forming a hinge. The tissue would act as a flap. The flap would then be engaged and articulated so as to expose the inside surface of the flat and the cut surface of the cornea. Typically, the length of the flap as measured from the hinge is 8-9 mm, and the depth of the

flap at its thickest point is nominally 160 microns. Choice of the flap thickness is dependent on the amount of correction required.

The flap would be held by flap shaping fixture **32**, which consists of pins **34** and base **36** as shown in FIG. **6(a)** and FIG. **6(b)**. The pins can be adjusted to provide more curvature to the flap.

After cutting the cornea **19**, the operator at step **44** would acquire a three dimensional profile of the patient's eye using monitor **7** and the system or operator would modify the nominal ablation pattern to set axis, depth of ablation versus distance and angle and set the maximum radial distance versus angle. Monitors for profiling corneas are well-known in the art and are commercially sold under the trade name Keratron and manufactured by Optikon 2000. Details on corneal profilers may be found in U.S. Pat. No. 4,863,260 issued to Gersten et al. and assigned to Computed Anatomy Inc. U.S. Pat. 4,863,260 is expressly incorporated by reference.

After modification of the ablation pattern based on the patient's corneal profile, and actual corneal position, the corneal pattern verifier **5** would enter the desired ablation pattern as a data entry to computer **12**. The modification would be monitored by a physician experienced in corrective eye surgery, who could override the correction. The remaining process would then be done as described. The automation of the process provides the advantage of completing the procedure in a few seconds.

At step **46**, computer **12** would first adjust the micromirrors of DMD **10** to the calculated ablation pattern. Laser **18** would then pulse a single time at step **48.** Laser **18** typically would be an argon fluoride laser. However, any pulsed or strobed source of radiation including lasers, flash lamps and light emitting diodes may be used provided that the source produces radiation at the appropriate wavelength for ablation of the corneal tissue. In the present art, the only known satisfactory excimer laser wavelength for ablation of corneal tissues without damaging surrounding tissue is 193 nanometers; however the scope of the present invention is not limited to that wavelength or the use of excimer lasers.

During the pulsing sequence, the pulse would travel from laser **18** and pass through beam homogenizing and collimating optic **13**, which transforms the beam to a homogenous and collimated beam with a uniform cross-sectional energy density. Optic **13** also reduces the divergence of the pulse and increases its width. The pulse would then travel to DMD **10** and would be reflected off DMD (10) and splitter **9** in accordance to predetermined pattern of

micromirrors. Mirror **9** directs a portion of the beam to Lens **4** and then pattern detector **2**. The remainder of the beam passes through conventional imaging optic **14** and imports ablating energy to cornea **19**. Pattern detector **2** passes its output to pattern verifier **6** and then to computer **12**.

After the pulse at step **48**, computer **12** at steps **50** and **54** using the information supplied by pattern detector **2** and pattern verifier **6** determines if the beam pattern being reflected off DMD **10** matches the programmed pattern. If there is no match, then the process is terminated and the operator is notified of machine failure as shown in step **52**. If the match is within preset acceptable limits, then the process continues.

At step **56**(assuming that the process has not been halted on account of machine failure), corneal monitor **7** would acquire a three-dimensional profile of the patient's eye. This profiler using the components that are presently commercially available requires 40 to 100 milliseconds. If the measured profile matches the desired profile, then the process would be halted and the operator would be notified of successful completion of the procedure at step **60** and **62**..

In most cases, however, prior to completion of the procedure, it will be necessary to calculate a new ablation pattern due to various factors the actual ablation action pattern may not be as contemplated. These factors include non-uniform density of corneal tissue and slight eye movements. Accordingly, at step **58** if the measured profile does not match the desired profile at each individual pixel, then computer **12** at step **64** would then calculate a new ablation pattern based on the measurement.

After calculation of new ablation pattern, computer **12** would determine at step **66** if the derived profile can in fact be created. If it cannot be created, then the process would be halted and the operator would be notified of that condition at step **68**. If the pattern can be physically created, then the process would continue in a closed loop operation beginning with step **46**.

FIG. **5** shows another preferred embodiment of the invention in which laser **12** would emit low power radiation at step **48a** (which substitutes for step **48** in FIG. **4**) and would be reflected by DMD **10**. In addition, there would be a step **54a** for the ablation pulse. The detector in that case would be photo-electronic camera. This combination would replace the corneal monitor **7**. The lower power laser could also be a separate helium neon laser.

The actual ablation would be carried out first on the cut surface of the cornea **19** and then on the inside surface of flap **30**. This procedure represents an improvement over the current art since it is more difficult to achieve a precise predetermined ablation profile on the cut surface of the cornea than on the inside surface of the flap. As a result, it is advantageous to make a gross correction on the cut surface of the cornea and then make a fine correction on the inside surface of the flap. It is understood that with sufficient thickness of the flap, the entire sculpting correction could be performed on the inside of the flap surface, leaving the cut cornea surface unmodified. The preferred embodiment of the invention also permits complicated three-dimensional profiles to be achieved as shown in FIG. **3(c)**.

Referring now to FIG **3(a)** shows the flap **30** after it has been articulated and engaged by the compliant support device. FIG. **3(b)** shows ablation of both the corneal flap **30** and cornea **19**. FIG **3(c)** shows the placement of the flap back on the cornea.

FIG. **6(a)** and FIG. **6(b)** illustrate two more preferred embodiments of the compliant support device. The support devices consist of a matrix of movable pins that are digitally controlled for protrusion length. Locating the pin tips at different heights combined with matrix information allows for accurate reading of the surface profile. This facilitates the ablation process because only the area is elevated from the flat plan.

FIG. **7(a) and** FIG. **7(b)** illustrates another preferred embodiment of the invention in which a corneal transplant **104** is substituted for flap **30**. In other respects, this preferred embodiment resembles the first preferred embodiment.

While various advantageous embodiments have been chosen to illustrate the invention, it will be understood by those skilled in the art that various changes and modifications can be made without departing from the scope of the invention as defined in the following claims.

What Is Claimed:

1. A system for ablating a workpiece including:
   - a device (18) for producing pulses of electromagnetic radiation;
   - a computer controlled programmable array of reflecting surfaces (10)wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions, said array thereby selectively directing portions of said pulses to said workpiece (19);
   - a computer (12) for controlling said array (10) to achieve the desired pattern of ablation;
   - a monitoring device (7) for determining the amount of ablation of said workpiece (19) after each of said pulses; and
   - a device (8) for providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array after receiving information on the degree of ablation from the monitoring device (7).

2. A method for ablating a workpiece including the steps of:
   - producing said workpiece (19);
   - producing pulses of electromagnetic radiation;
   - selectively directing portions of said pules to said workpiece using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
   - controlling said array using a computer (12) to achieve the desired pattern of ablation;
   - determining the amount of ablation of said workpiece using a monitoring device (7) after each of said pulses; and
   - providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (12) of said array (10) after receiving information on the degree of ablation from the monitoring device.

3. The system described in Claim 1 wherein the workpiece (19) is a human cornea.

4. The method described in Claim 2 wherein the workpiece (19) is a human cornea.

5. A method for ablating a cornea of a patient to correct vision including the steps of:
   - preparing said patient (40)
   - cutting the surface of said cornea (41) and articulating the flap of tissue formed thereby;
   - producing pulses of electromagnetic radiation (48)
   - selectively directing portions of said pulses to said flap using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
   - controlling said array using a computer (12) to achieve the desired pattern of ablation;
   - determining the amount of ablation of said flap using a monitoring device (7) after each of said pulses; and
   - providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

6. A method for ablating a cornea of a patient to correct vision including the steps of:
   - preparing said patient (40);
   - cutting the surface of said cornea (41) and articulating the flap of tissue formed thereby;
   - selectively directing portions of said pulses to the main body of said cornea using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
   - controlling said array using a computer (12) to achieve the desired pattern of ablation;

- determining the amount of ablation of main body using a monitoring device (7) after each of said pulses; and
- providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).
- producing pulses of electromagnetic radiation (48);
- selectively directing portions of said pulses to the main body of said flap (19) using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
- controlling said array using a computer (12) to achieve the desired pattern of ablation;
- determining the amount of ablation of main body using a monitoring device (7) after each of said pulses; and
- providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

7. A system for writing a pattern by ablation on a deposit layer on a silicon wafer including:
   - a device for producing pulses of electromagnetic radiation (18);
   - a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions, said array thereby selectively directing portions of said pules to said deposit layer (19);
   - a computer (12) for controlling said array (10) to achieve the desired pattern of ablation;
   - a monitoring device (7) for determining the amount of ablation of said deposit layer after each of said pulses; and
   - a device (8) for providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces

(22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

8. A method for writing a pattern by ablation on a deposit layer on a silicon wafer including the steps of:

- producing said deposit layer;
- producing pulses of electromagnetic radiation;
- selectively directing portions of said pules to said deposit layer using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
- controlling said array using a computer (12) to achieve the desired pattern of ablation;
- determining the amount of ablation of said deposit layer using a monitoring device (7) after each of said pulses; and
- providing information from said monitoring device to said computer for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

9. A system for writing a bar code pattern by ablation on a workpiece including:

- a device for producing pulses of electromagnetic radiation (18);
- a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions, said array thereby selectively directing portions of said pules to said workpiece (19);
- a computer (12) for controlling said array (10) to achieve the desired pattern of ablation;
- a monitoring device (7) for determining the amount of ablation of said workpiece (19) after each of said pulses; and
- a device (8) for providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces

(22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

10. A method for writing a bar code pattern by ablation on a workpiece including the steps of:

- producing said workpiece;
- producing pulses of electromagnetic radiation;
- selectively directing portions of said pules to said deposit layer using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
- controlling said array using a computer (12) to achieve the desired pattern of ablation;
- determining the amount of ablation of said deposit layer using a monitoring device (7) after each of said pulses; and
- providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

11. A system for writing a numerical pattern by ablation on a workpiece including:

- a device for producing pulses of electromagnetic radiation (18);
- a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions, said array thereby selectively directing portions of said pules to said workpiece(19);
- a computer (12) for controlling said array (10) to achieve the desired pattern of ablation;
- a monitoring device (7) for determining the amount of ablation of said workpiece (19) after each of said pulses; and
- a device (8) for providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

12. A method for writing a numerical pattern by ablation on a workpiece including the steps of:

- producing said workpiece;
- producing pulses of electromagnetic radiation;
- selectively directing portions of said pules to said deposit layer using a computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions;
- controlling said array using a computer (12) to achieve the desired pattern of ablation;
- determining the amount of ablation of said deposit layer using a monitoring device (7) after each of said pulses; and
- providing information from said monitoring device (7) to said computer (12) for adjusting the reflecting positions of said reflecting surfaces (22) of said array (10) after receiving information on the degree of ablation from the monitoring device (7).

13. A computer controlled programmable array of reflecting surfaces (10) wherein each of said reflecting surfaces (22) may be in one of a plurality of reflecting positions, which array is enclosed in a housing at least one of whose sides is a transparent material (26) that permits the passage of ultra-violet light.

14. The device described in claim **11**, wherein the transparent material (26) is composed of ultra-violet grade synthetic fused silica.

15. The device described in claim **11**, wherein said transparent material (26) is composed of a fluorine based material.

16. The device described in claim **11**, wherein said transparent material (26) is composed of magnesium fluoride.

17. The device described in claim **11**, wherein said transparent material (26) is composed of fused silica.

18. The device described in claim 11, wherein said transparent material (26) is composed of synthetic fused silica.

19. The device described in claim 11, wherein said transparent material (26) is composed of calcium fluoride.

20. The device described in claim 11, wherein said transparent material (26) is composed of lithium fluoride.

21. The device described in claim 11, wherein said transparent material (26) is composed of barium fluoride.

FIG. 1

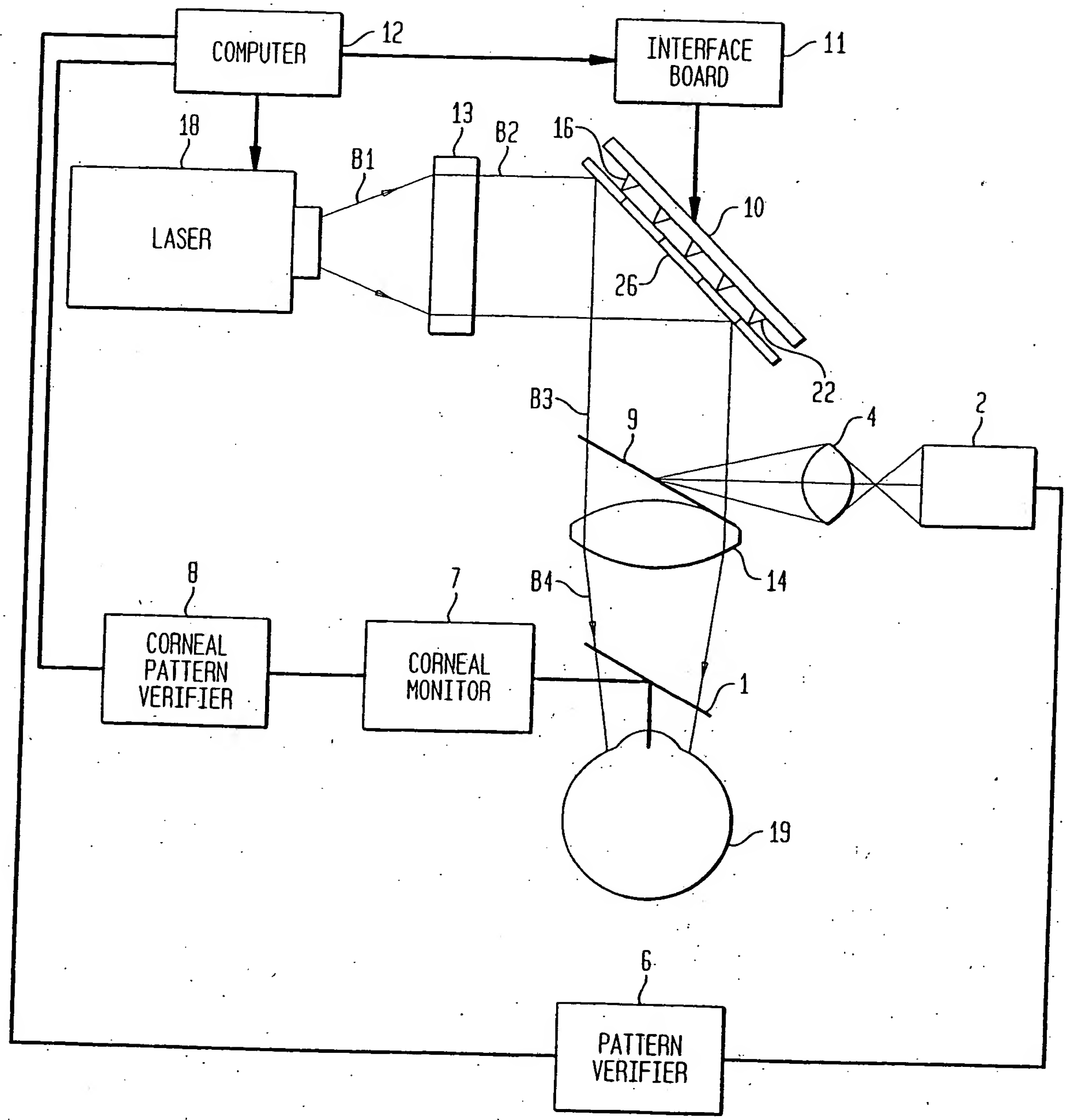

COMPUTER
12
INTERFACE BOARD
11
18
LASER
B1
13
B2
16
10
26
22
B3
9
4
2
14
B4
8
CORNEAL PATTERN VERIFIER
7
CORNEAL MONITOR
1
19
6
PATTERN VERIFIER

FIG. 2

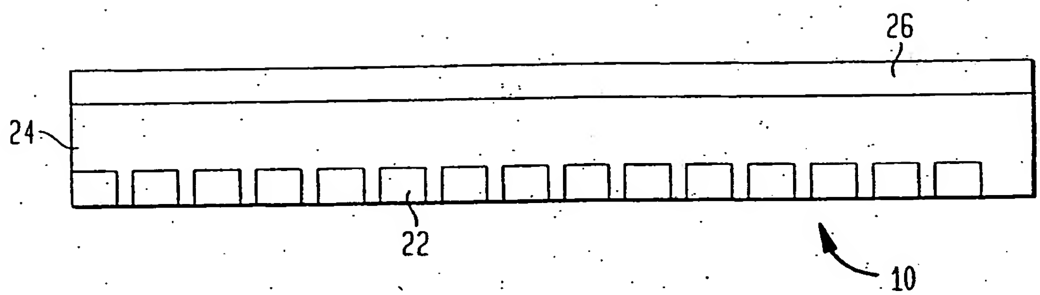

26
24
22
10

FIG. 3A

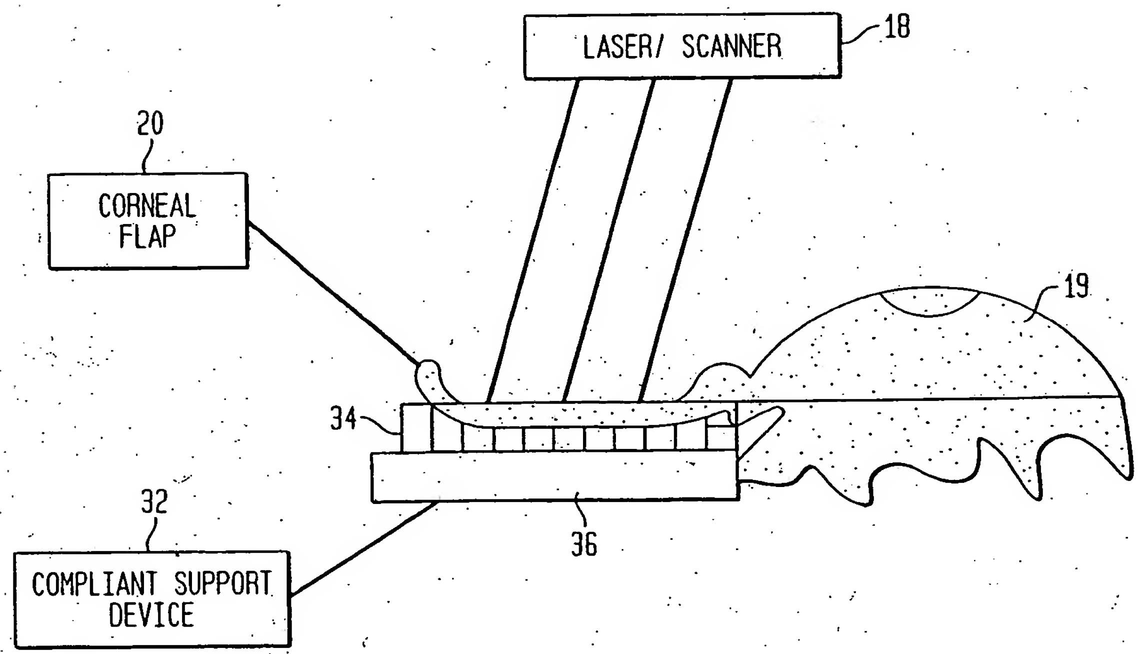

LASER/ SCANNER
18
20
CORNEAL FLAP
19
34
32
36
COMPLIANT SUPPORT DEVICE

FIG. 3B

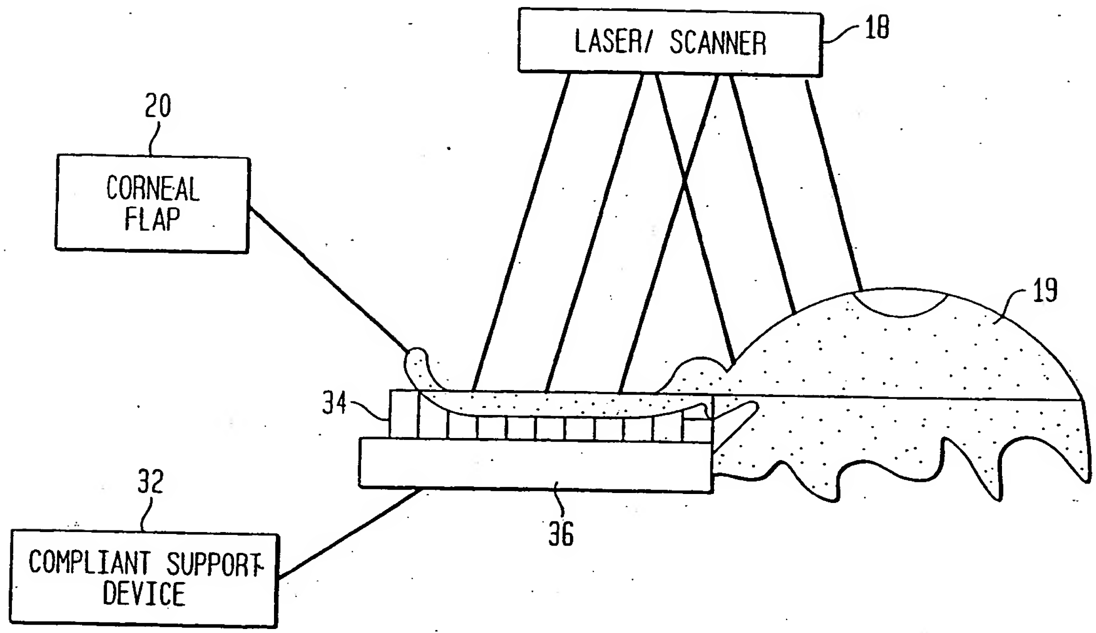

LASER/ SCANNER
18
20
CORNEAL FLAP
19
34
32
36
COMPLIANT SUPPORT DEVICE

FIG. 3C

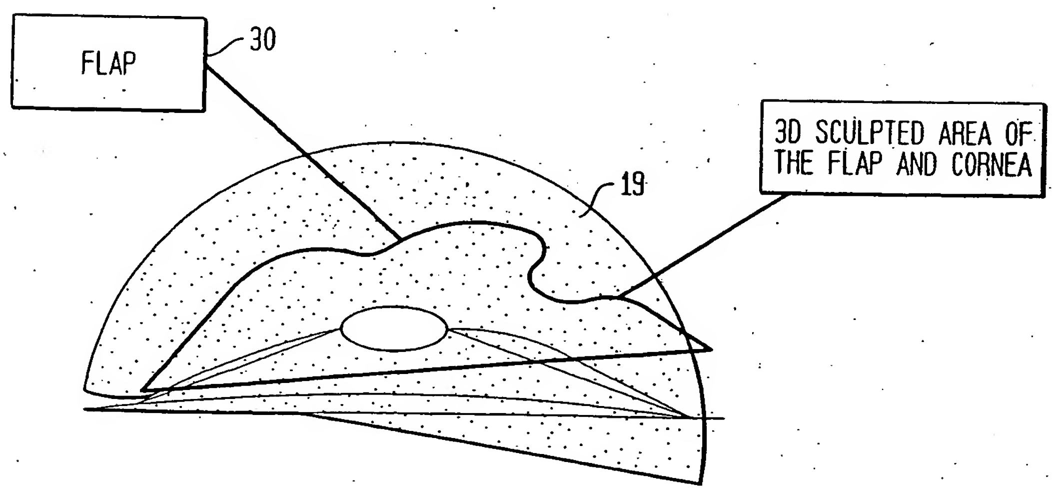

FLAP
30
3D SCULPTED AREA OF THE FLAP AND CORNEA
19

FIG. 4

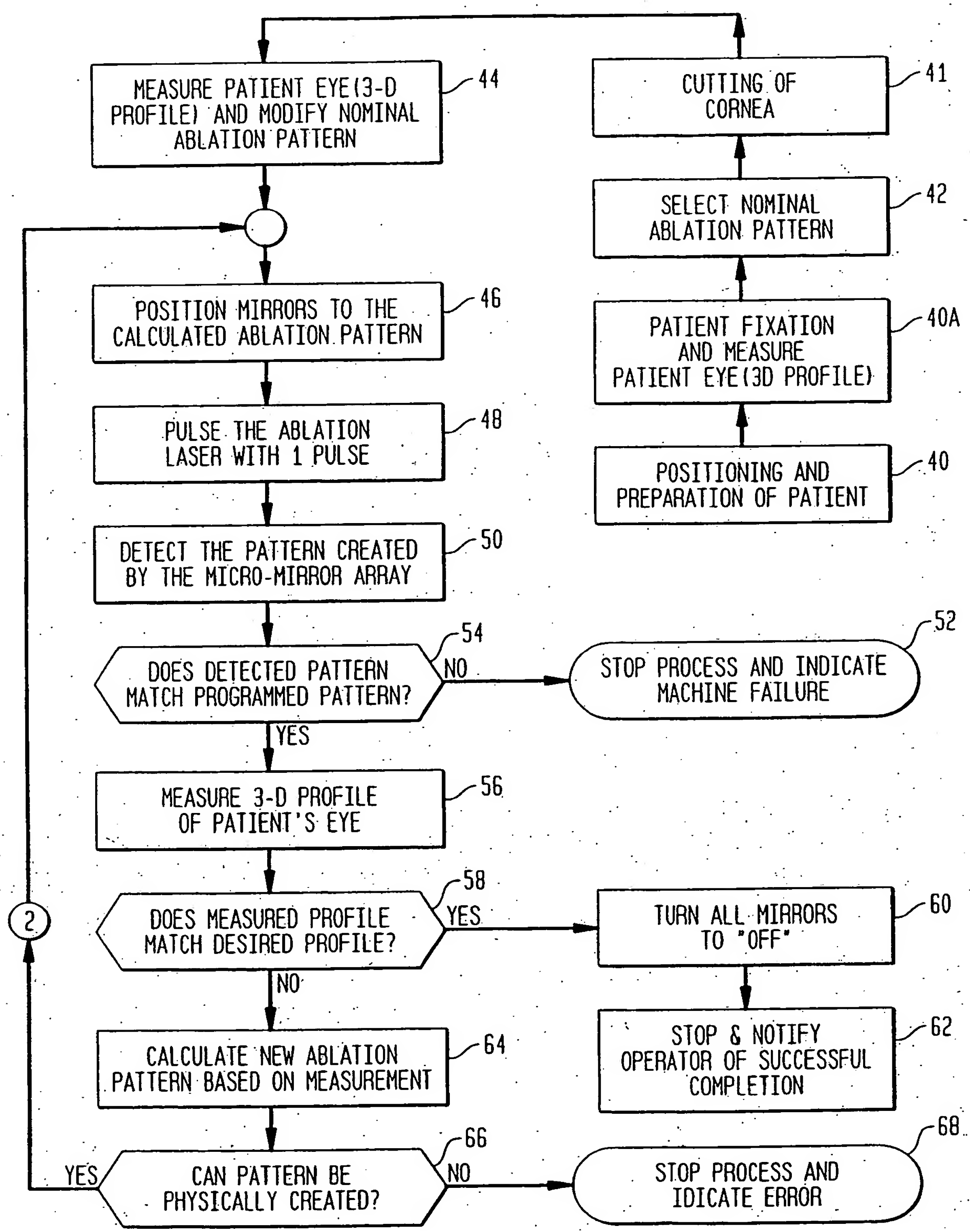

MEASURE PATIENT EYE (3-D PROFILE) AND MODIFY NOMINAL ABLATION PATTERN
44
CUTTING OF CORNEA
41
SELECT NOMINAL ABLATION PATTERN
42
PATIENT FIXATION AND MEASURE PATIENT EYE (3D PROFILE)
40A
POSITIONING AND PREPARATION OF PATIENT
40
POSITION MIRRORS TO THE CALCULATED ABLATION PATTERN
46
PULSE THE ABLATION LASER WITH 1 PULSE
48
DETECT THE PATTERN CREATED BY THE MICRO-MIRROR ARRAY
50
DOES DETECTED PATTERN MATCH PROGRAMMED PATTERN?
54
NO
STOP PROCESS AND INDICATE MACHINE FAILURE
52
YES
MEASURE 3-D PROFILE OF PATIENT'S EYE
56
DOES MEASURED PROFILE MATCH DESIRED PROFILE?
58
YES
TURN ALL MIRRORS TO "OFF"
60
STOP & NOTIFY OPERATOR OF SUCCESSFUL COMPLETION
62
NO
CALCULATE NEW ABLATION PATTERN BASED ON MEASUREMENT
64
2
YES
CAN PATTERN BE PHYSICALLY CREATED?
66
NO
STOP PROCESS AND IDICATE ERROR
68

FIG. 5

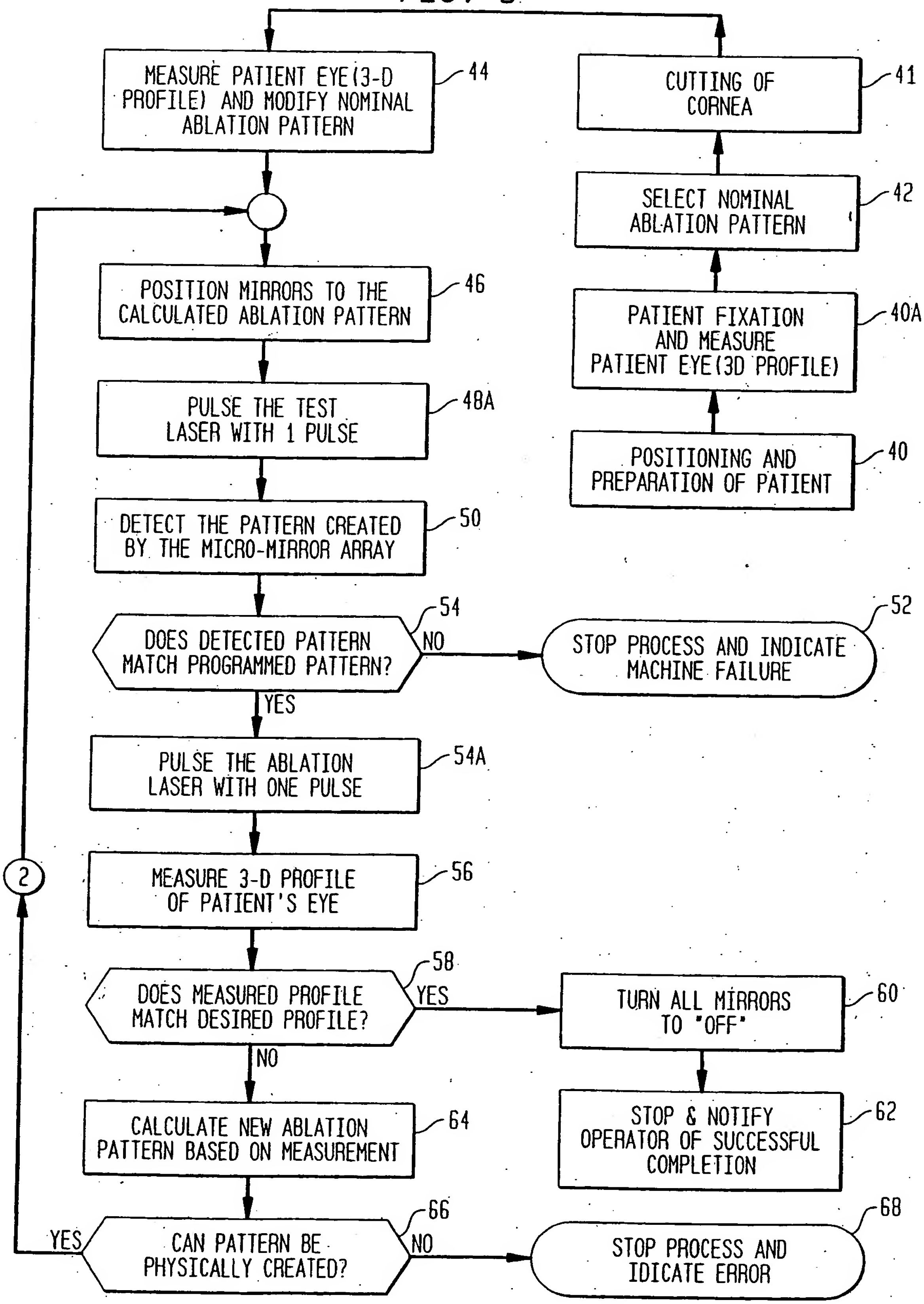

MEASURE PATIENT EYE (3-D PROFILE) AND MODIFY NOMINAL ABLATION PATTERN
44
CUTTING OF CORNEA
41
SELECT NOMINAL ABLATION PATTERN
42
PATIENT FIXATION AND MEASURE PATIENT EYE (3D PROFILE)
40A
POSITIONING AND PREPARATION OF PATIENT
40
POSITION MIRRORS TO THE CALCULATED ABLATION PATTERN
46
PULSE THE TEST LASER WITH 1 PULSE
48A
DETECT THE PATTERN CREATED BY THE MICRO-MIRROR ARRAY
50
DOES DETECTED PATTERN MATCH PROGRAMMED PATTERN?
54
NO
YES
STOP PROCESS AND INDICATE MACHINE FAILURE
52
PULSE THE ABLATION LASER WITH ONE PULSE
54A
MEASURE 3-D PROFILE OF PATIENT'S EYE
56
2
DOES MEASURED PROFILE MATCH DESIRED PROFILE?
58
YES
NO
TURN ALL MIRRORS TO "OFF"
60
STOP & NOTIFY OPERATOR OF SUCCESSFUL COMPLETION
62
CALCULATE NEW ABLATION PATTERN BASED ON MEASUREMENT
64
CAN PATTERN BE PHYSICALLY CREATED?
66
YES
NO
STOP PROCESS AND IDICATE ERROR
68

FIG. 6A

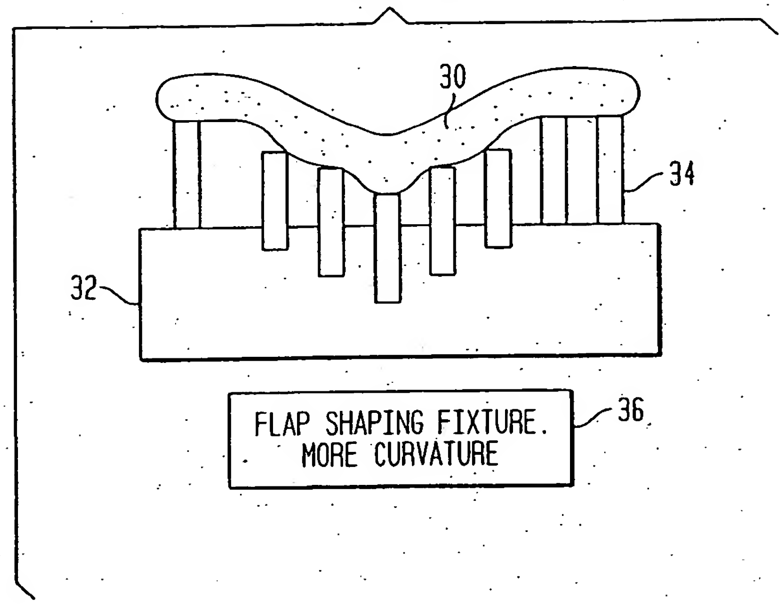

30
34
32
FLAP SHAPING FIXTURE.
MORE CURVATURE
36

FIG. 6B

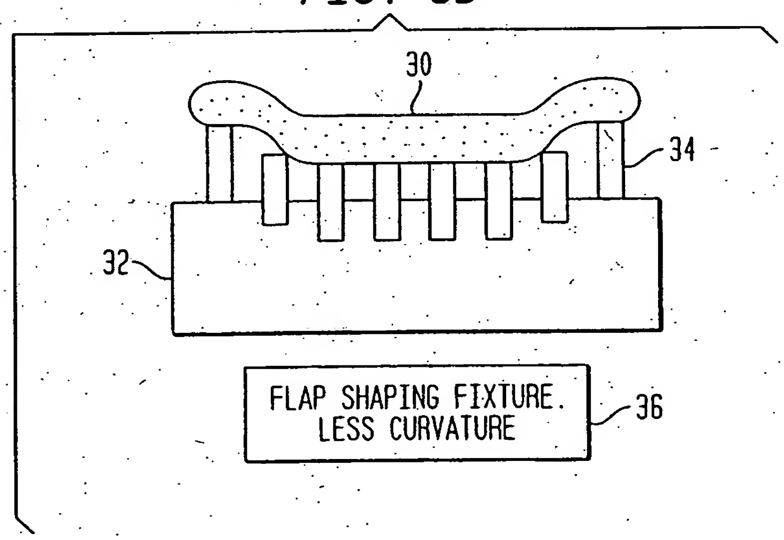
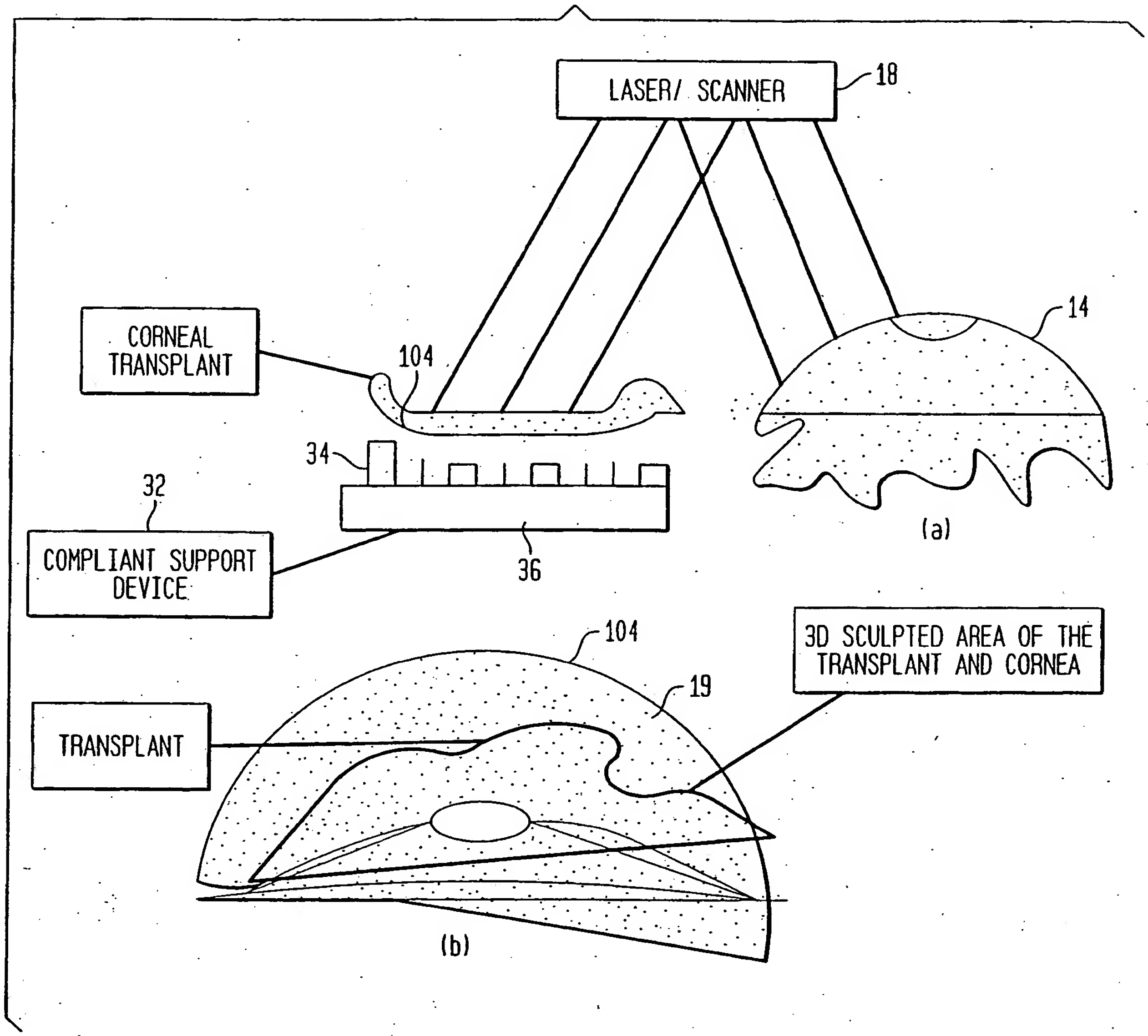

30
34
32
FLAP SHAPING FIXTURE.
LESS CURVATURE
36

FIG. 7


LASER/ SCANNER
18
14
CORNEAL TRANSPLANT
104
34
32
COMPLIANT SUPPORT DEVICE
36
(a)
104
19
3D SCULPTED AREA OF THE TRANSPLANT AND CORNEA
TRANSPLANT
(b)